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B.7 FIRE TEST ON NORMAL AND HIGH-STRENGTH REINFORCED CONCRETE COLUMNS

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ABSTRACT

The occurrence of spalling is a major factor in determining the fire resistance of concrete constructions. This paper presents an experimental investigation of fire spalling of normal and high strength concrete in order to provide recommendations for fire safety of constructions. Six short reinforced concrete columns in compression were studied under standard fire conditions. Parameters considered were: reinforcement, by number and diameter of steel rebars, and type of concrete (normal strength concrete and high strength concrete). Test results showed comparable behavior and no spalling of normal strength concrete columns and spalling with a considerable reduction in fire resistance of high-strength concrete.

INTRODUCTION

Although reinforced concrete elements generally exhibit satisfactory behavior at high temperatures, especially when subjected to fire, sudden spalling of external concrete layers is sometimes observed and, consequently, the longitudinal reinforcement may be exposed directly to fire. In such cases failure occurs prematurely and sometimes fire resistance is reduced to half of the original value. The occurrence of spalling is a major factor in determining the fire resistance of concrete constructions (1). Many references in the literature refer to this phenomenon (2,3).

Among the factors that have been identified as influencing spalling of concrete structures subjected to fire, some are related to material properties, such as porosity, tensile strength, thermal elongations, moisture content or thermal properties. Other factors, although directly influenced by the material properties, are related to the structure, the stress distribution depending on the loading and support system, and the presence of steel rebars. Analytical study of spalling should involve consideration of coupled thermal, mechanical and hydraulic phenomena.

A recent experimental program of full-scale tests made on 21 loaded concrete columns (4) showed that Eurocode 2 recommendations (5) are not safe, even when applied to normal strength concrete. Although the rules mentioned in Eurocode 2 suggest that no spalling should occur, some significant spalling did happen during the tests. It was also found that spalling was much more likely to occur in columns with longitudinal rebars of large diameters than in columns with smaller bars. As the first experimental program was not particularly dedicated to spalling, a new experimental program was set up to analyze this question for normal and high-strength concrete columns.

STUDY OBJECTIVES AND RESEARCH SIGNIFICANCE

Study objective was to quantify some of the parameters influencing fire spalling of normal and high-strength concrete in order to provide recommendations for fire safe constructions. Experiments were performed and numerical simulation was planned in order to compare experimental and numerical results. Six short reinforced concrete columns of the same dimensions submitted to compression were studied under fire conditions. The following parameters were considered: reinforcement, by number and diameter of steel rebars; and type of concrete (normal strength concrete C20 and C50, and high strength concrete C90).

The goal of this research work was first to compare the structural behavior of normal and high-strength concrete under fire conditions. Another purpose was to examine a structural effect noticed in the previous experimental study (4), i.e., the influence of the diameter of the rebars on spalling of concrete

EXPERIMENTAL PROGRAM

Test series and mix proportions

Concrete columns were tested at the University of Liège, in Belgium. Six short columns with identical : square 290 x 290 mm cross sections, 2.10 m long were tested in one of the furnaces of the Fire Test Laboratory, University of Liège. The length of the columns was limited by the height of the existing furnace. Test series included columns made of three different mix compositions (Table 1): normal strength concrete C30 and C50, and high strength concrete C90, and 2 different longitudinal reinforcement types, 8 Φ 12 and 4 Φ 25 (Figure 1). Concrete cover was 3 cm. Stirrups with 8 mm diameter were placed 200 mm apart along the columns, except at the ends, where 100 mm spacing was used along the remaining 300 mm (Figure 2). Another three columns, one for each of the mix compositions, were cast in order to determine material characteristics only (Figure 3, section type 1). Compressive strength and tensile strength were determined on 112.5 x 246 mm, 28-day old cores drilled from the concrete columns without reinforcement .

Compression and Fire Tests

Each column was simply supported at the ends. The furnace was provided with an external frame specially designed to apply compressive and tensile stresses. Specimens were loaded by means of 2 double-acting (compressive and tensile) hydraulic jacks.

Thirty two thermocouples were placed in each column before casting of concrete in order to measure temperature evolution. The thermocouples were symmetrically placed at significant locations in the cross sections, such as: in the corners of the concrete section next to stirrups, on both sides of the longitudinal reinforcements, in the concrete core, and on the longitudinal axis.

Thermocouples were placed in 4 different sections along the column: in 2 sections containing stirrups, 9 thermocouples per section, and in 2 sections without stirrups, 7 thermocouples per section (Figures 4 and 5).

Test procedure

The columns were tested in compression and under standard fire conditions. A compressive force representing 50% of the column design load (6,7) was applied first (Table 2). Heating was applied in the gas furnace according to the standard ISO 834 curve (8). The change in length of the columns and temperatures in the 32 thermocouples were recorded every minute during the tests. The column condition was examined basically every 30 minutes during the fire tests, or more frequently when spalling was noticed. This was based on previous research and observations suggesting that spalling usually occurs within a time frame between 30 and 60 minutes after the beginning of heating.

EXPERIMENTAL RESULTS

Comparable behavior of normal strength concrete columns was observed in the experimental program. Both C20 and C50 columns showed a few longitudinal cracks near the edges (Figure 8), with progressive crushing of concrete and buckling of the steel rebars (Figures 7 to 9). Fire resistance proved comparable (Table 3 and Figure 6). High-strength concrete columns showed early spalling at the corners, premature heating of the steel rebars in the reduced section, buckling of the steel rebars just before a sudden failure by crushing of the concrete core (Figure 10). Consequently, a considerable reduction in fire resistance was noticed.

COMMENTS AND CONCLUSIONS

1. Spalling of normal strength concrete columns under fire action was not noticed.

2. High strength concrete columns showed spalling phenomena after 8 minutes (C90, 8 ϕ 12 mm) and 11-12 minutes (C90 4 ϕ 25 mm). In both cases, corner spalling was observed. This type of spalling also referred to as sloughing-off is a consequence of concrete losing its tensile strength at elevated temperatures, and has proved to be particularly significant in determining the fire resistance of columns (1). These experimental results confirm the fact that high strength concrete is more susceptible to spalling than normal strength concrete.

3. Longitudinal cracks along the main reinforcement were noticed for normal strength concrete after one hour of fire test and developed until the end of the test corresponding to crushing.
4. Tests showed that the material behavior has a more significant influence on failure than the structural behavior.
5. Experimental results proved that additional experimental research together with numerical modeling need to be carried out in order to better understand, the spalling phenomena.

FUTURE RESEARCH

1. Other parameters will be considered: the shape of the cross section and the load level.

   - circular cross sectional columns of same length (2.10 m), 300 mm diameter and 2 types of longitudinal reinforcement (6 ϕ 12 mm and 6 ϕ 20 mm) will be tested.

   - compressive load level will be 50% of the design load, as previously considered, and 70% of the design load, corresponding to a more important variable loading.

2. Attention will be focused on a better understanding of the spalling phenomena and of the most significant parameters to influence it and also on the development of a numerical model, considering coupling between thermal, mechanical and transport phenomena, to be included in the SAFIR computer code.

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REFERENCES

1. Connolly, R.J., Purkiss, J.A., Morris, W.A., The Spalling of Concrete in Fires, *First European Symposium on Fire Safety Science*, Zürich, 1995.
2.. Collet, Y., *L'Eclatement du Matèriau Bèton au cours d'un Incendie - Aperçu de la Littérature*. Group de Travail; Comportement du Matériau Béton en Fonction de la Température, CTIC, Bruxelles, May 1976.
3. CUR. *Spatten van Grindbeton en Lichtbeton bij Brand*, Rapport No. 98, Uitgave Betonvereniging, Zoetermeer, 1980.

4. Dotreppe, J.C., Baus, R., Franssen, J.M., Bruls, A., Dimensionnement des Colonnes en Béton Armé en Considérant le Problème de la Résistance au Feu, *Rapport Final I, Convention F.R.F.C.*, Service des Ponts et Charpentes, University of Liège, 1993.
5. Eurocode 2 - 1.2. Design of Concrete Structures. Part 10. Structural Fire Design., CEN November 1995.
6. Application of High Performance Concrete, Report of the CEB-FIP Working Group on High Strength/High Performance Concrete, *CEB Bulletin on Infromation No. 222*, November 1994.
7. Belgian Code NBN B15-103, 1977.
8. ISO. Fire Resistance Tests - Elements of Building Construction. International Standard 834, 1975.

Table 1. **Mix Compositions**

Concrete	Normal Strength Concrete				High Strength Concrete	
	C20		C50		C90	
Mix Ingredients	**kg**	**%**	**kg**	**%**	**kg**	**%**
Cement	280	1	410	1	47	1
Sand	800	2.86	750	1.83	780	1.66
Aggregate	1100	3.93	1050	2.56	1030	2.19
Water	185	0.66	175	0.43	145	0.31
Superplasicizer	-	-	10	0.024	12	0.026
Silica Fume	-	-	-	-	94	0.2

Note: river sand (Meuse), MS 0/5 mm
limestone aggregate, MSA 7/14 mm
cement P40 (C20), P50 (C50 and C90)
superplasticizerRHEOBUILD 2000PF
columns were cast at PARTEK-ERGON

Table 2. **Compressive Loading**

Test Series		50% Design Load (tf)	
		8 ϕ 12	4 ϕ 25
NSC	C20	46.46	63.71
	C50	96.40	113.01
HSC	C90	165.29	181.03

Table 3. Fire resistance

Concrete	**Fire Resistance (hours and minutes)**	
	8 ϕ 12	**4 ϕ 25**
C20	3 hours 54 minutes	3 hours 13 minutes
C50	2 hours 32 minutes	3 hours 29 minutes
C90	1 hour 46 minutes first spalling after 8 minutes	1 hour 29 minutes first spalling after 12 minutes

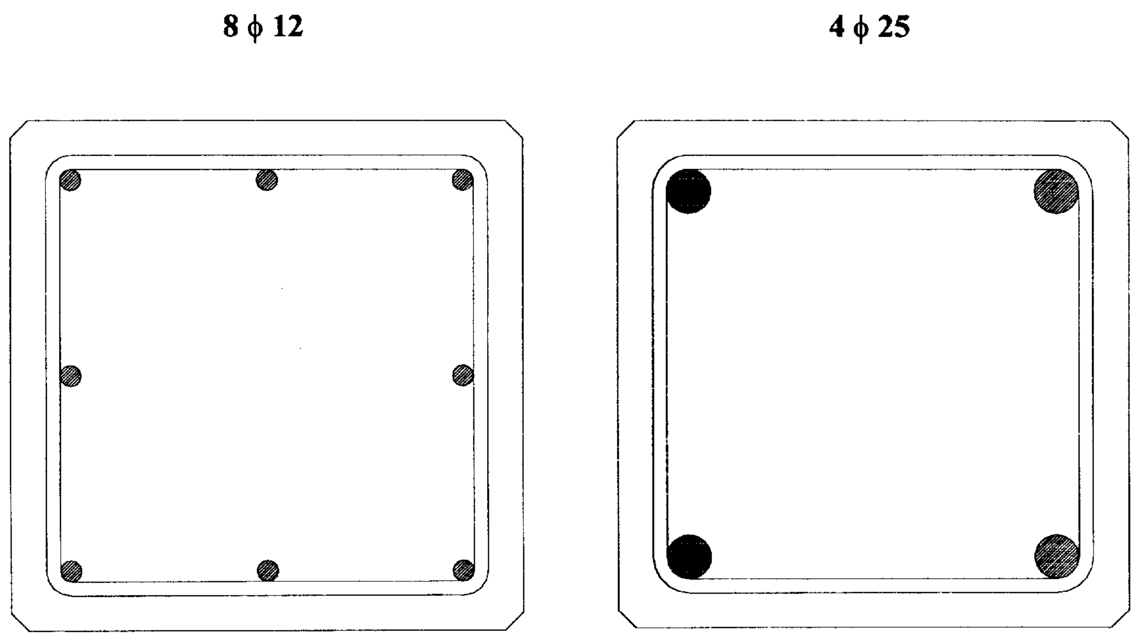


Figure 1. Concrete cross sections (29 cm x 29 cm); longitudinal reinforcement 8 ϕ 12 mm and 4 ϕ 25 mm. Concrete cover 3 cm

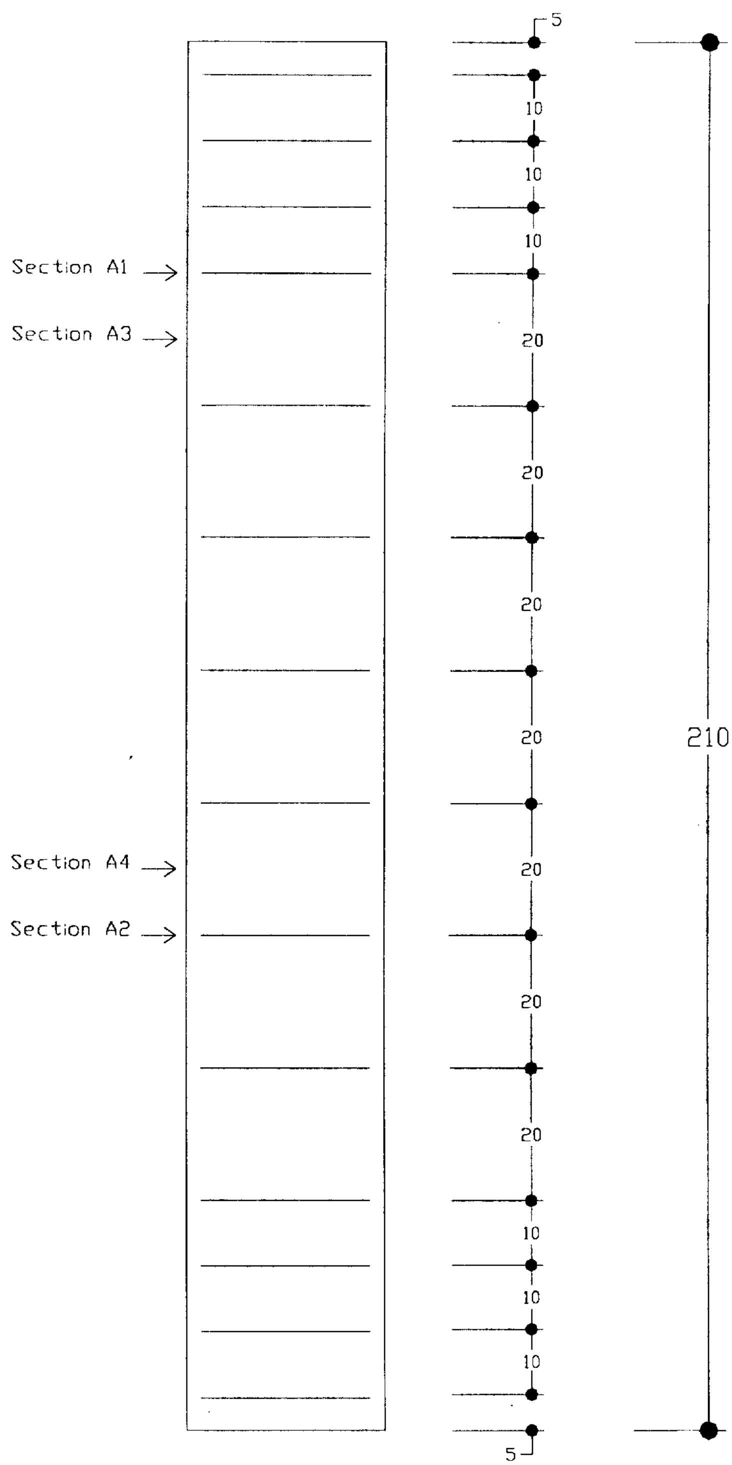


Figure 2. Section type 2 and 3. Position of thermocouples. Column used for fire test. Note: A1 and A2 sections with stirrups, A3 and A4 sections without stirrups

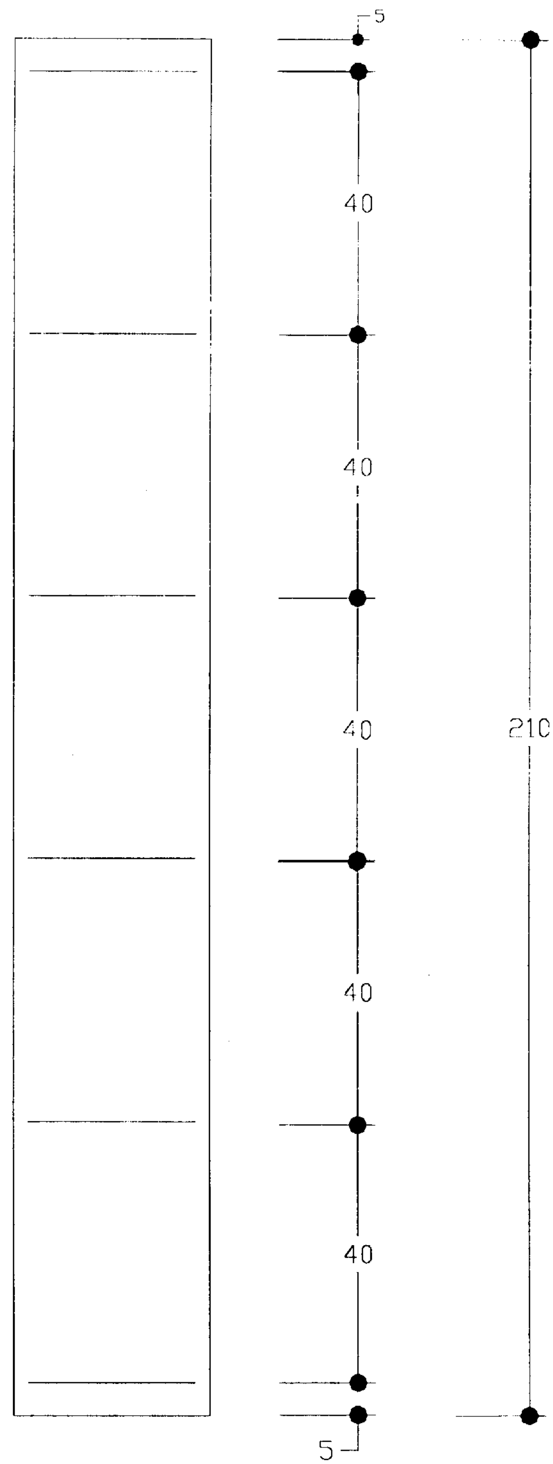
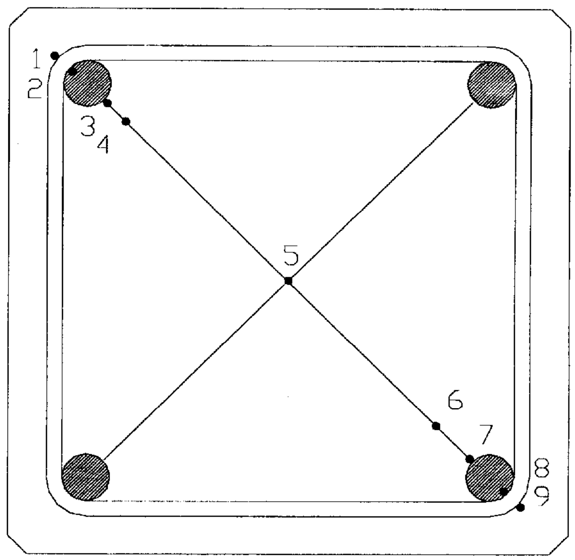


Figure 3. Section type 1. No thermocouples. Column used for material characteristic determination only. No fire test performed

Section A1



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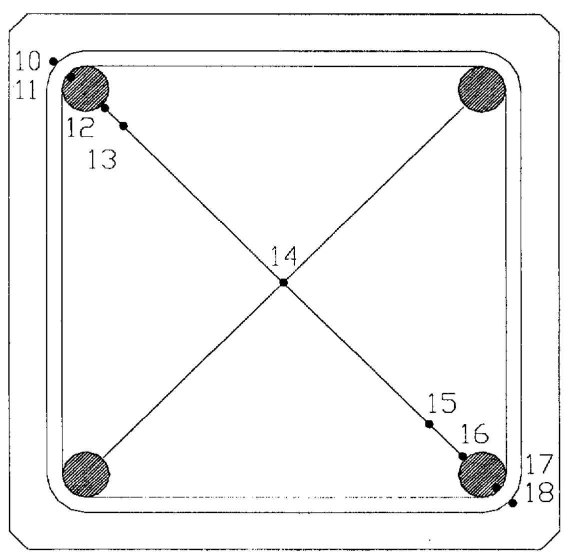
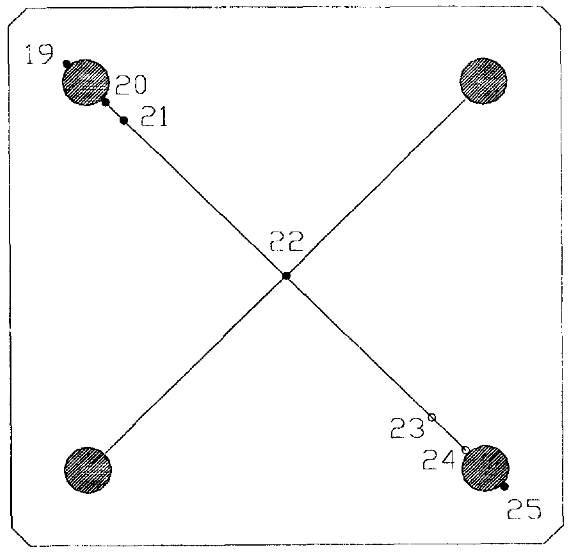


Figure 4. Position of thermocouples in the cross section. Sections with stirrups, 9 thermocouples per cross section

Section A3



Section A4

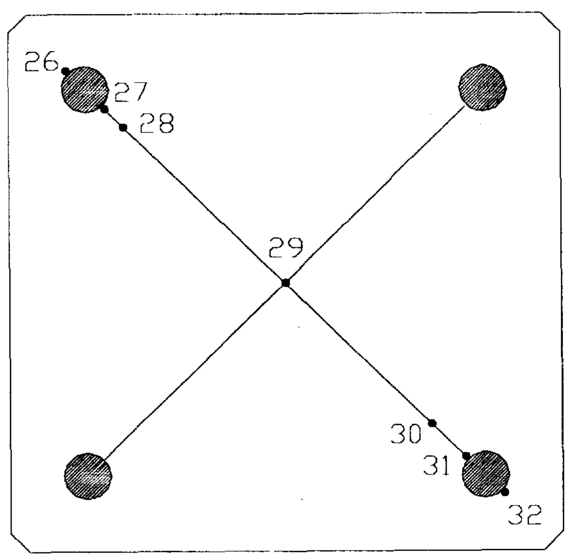


Figure 5. Position of thermocouples in the cross section. Sections without stirrups, 7 thermocouples per cross section

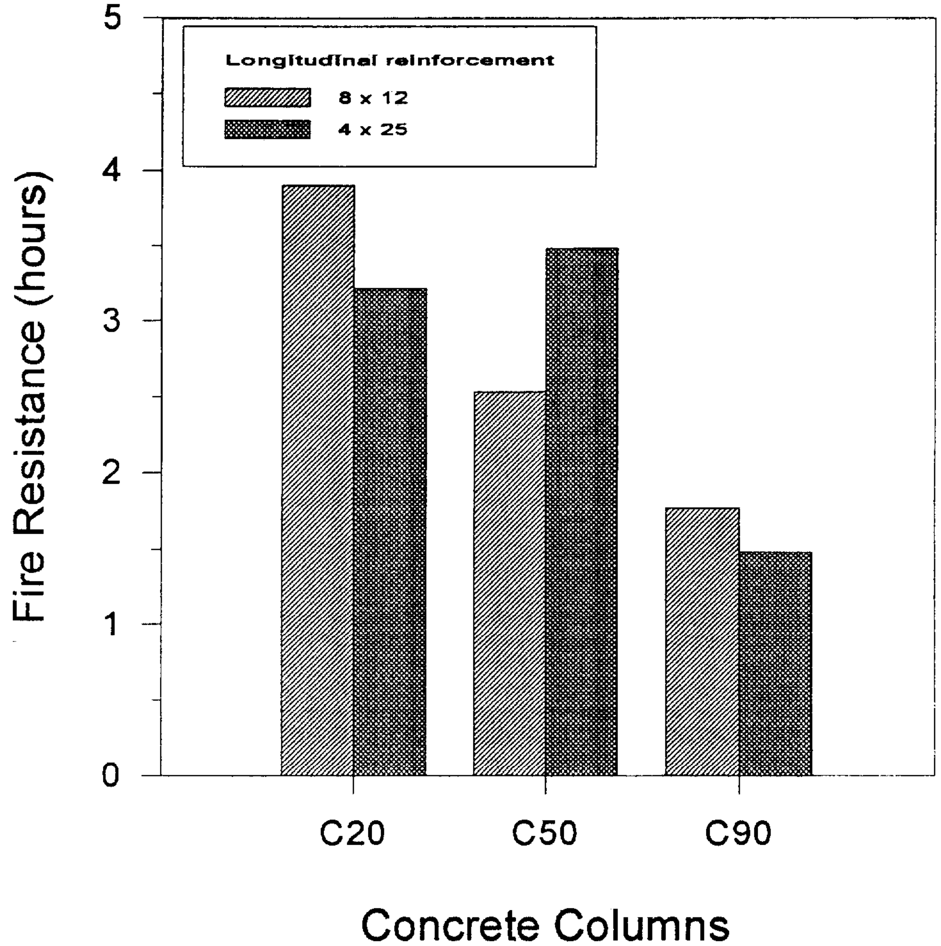
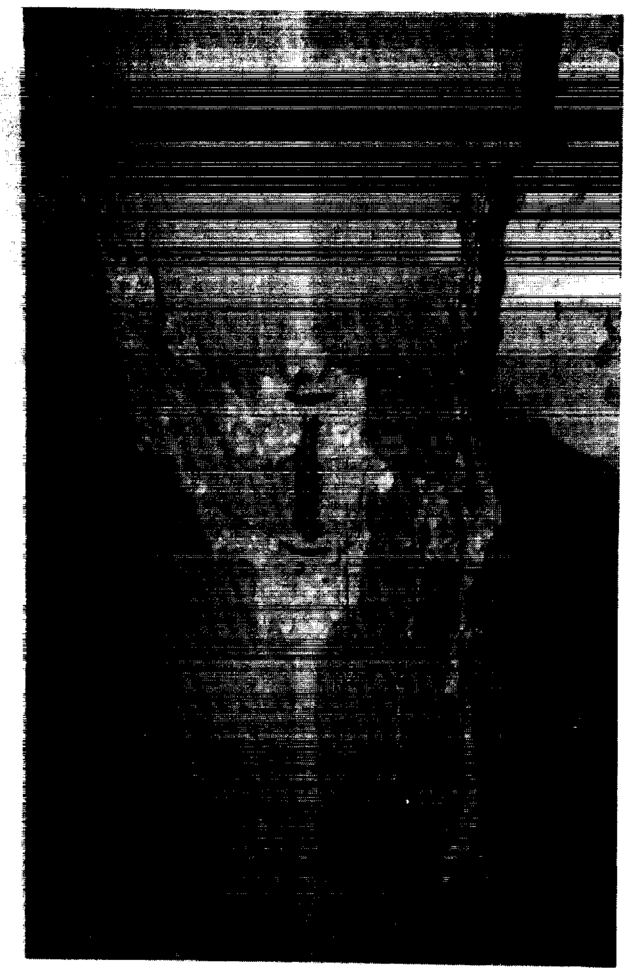


Figure 6. Fire resistance of concrete columns during tests

C20, 8 x 12



(b) C20, 4 x 25

Figure 7. Concrete columns after the test. Crushing of concrete and buckling of steel rebars

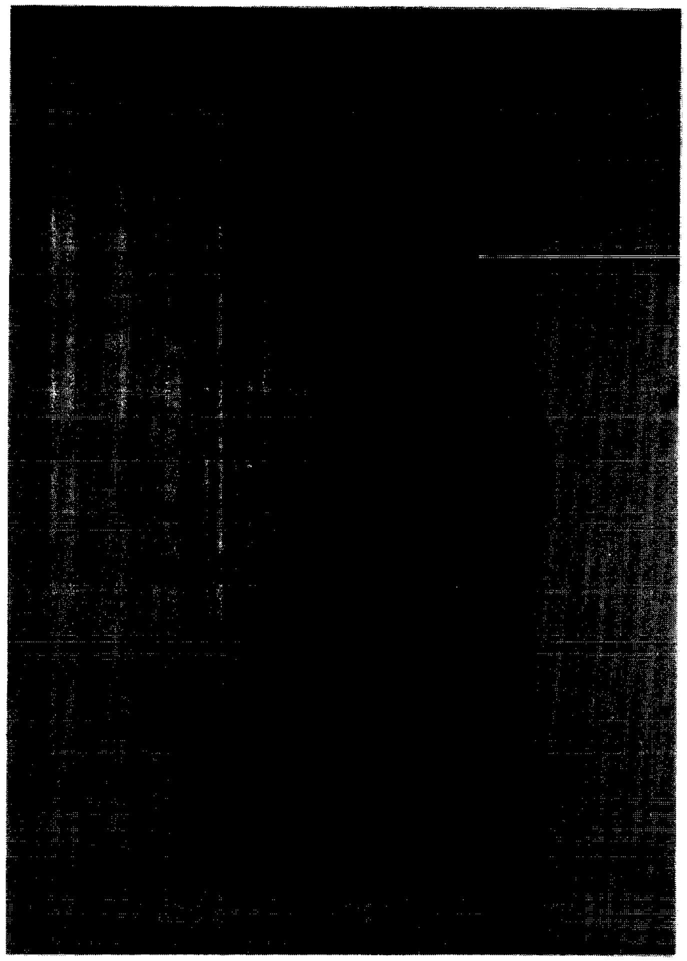
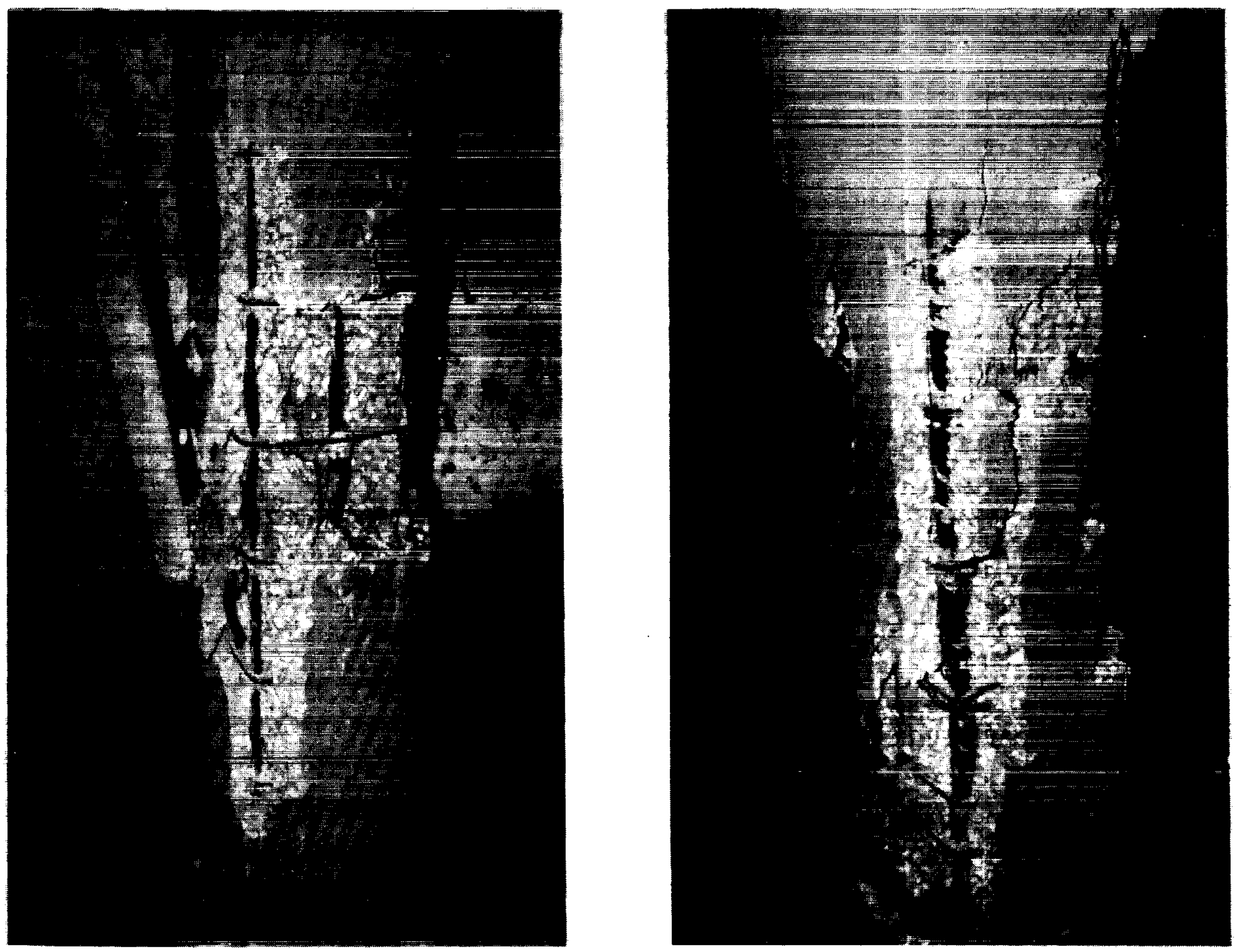
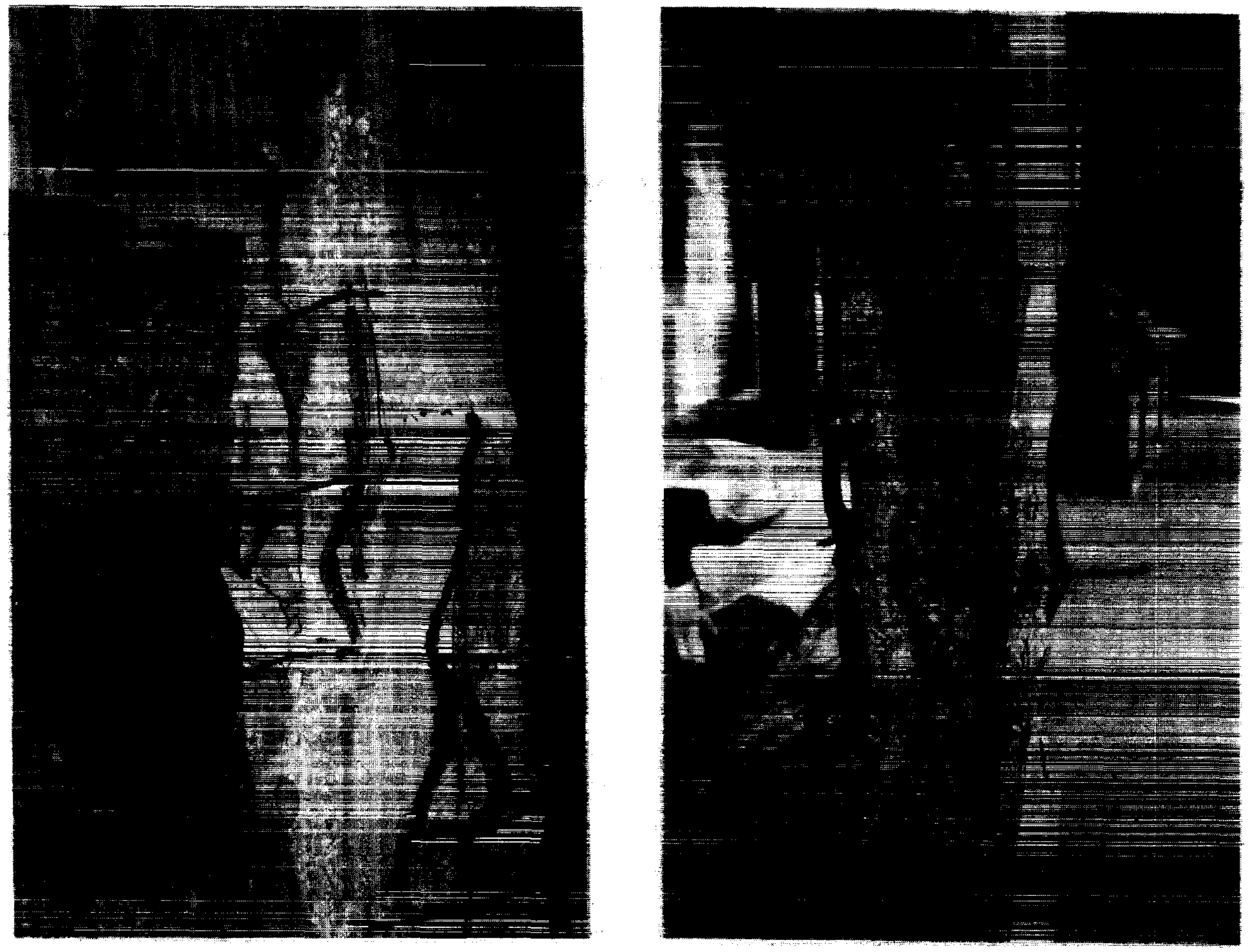


Figure 8. Concrete column during the test: C50, 8 x 12, t=1h 30 min.
Longitudinal cracks



(a) C50, 8 x 12　　　　(b) C50, 4 x 25

Figure 9. Concrete columns after the test. Crushing of concrete and buckling of steel rebars



(a) C90, 8 x 12 (b) C90, 4 x 25

Figure 10. Concrete columns after the test. Buckling of the steel rebars and crushing of the concrete core